COHERENT SYNCHRONIZATION OF CODE DIVISION MULTIPLE ACCESS
· SIGNALS

Donald C.D. Chang

Kar W. Yung

David C. Cheng

Frank A. Hagen

Ming U. Chang

John I. Novak, III

COHERENT SYNCHRONIZATION OF CODE DIVISION MULTIPLE ACCESS SIGNALS

Background of the Invention

The present invention relates generally to code division multiple access (CDMA) communications systems. More specifically, but without limitation thereto, the present invention relates to a method for reducing the

5   number of CDMA codes required for a number of subscribers serviced by multiple transponder platforms.

Traditionally, when multiple satellites become available over a given geographic location, two or more nearby users may not use the same frequency spectrum or

10   code space due to interference. Also, as the number of subscribers within a service area increases, the frequency bandwidth, the number of CDMA codes, or both must be increased to avoid interference from messages intended for other subscribers. The number of subscribers

15   is therefore limited by the frequency bandwidth and the number of CDMA codes.

Methods for reducing the number of CDMA codes for a service area effectively increase the bandwidth of the frequency spectrum by providing a greater portion of

20   the information in communications signals to be used for subscriber communication rather than for distinguishing one subscriber from another.

Although multiple transponder platforms, e.g. satellites, increase the system availability, their full

25   potential has been unrealized because of the limit on the number of users imposed by the assigned frequency bandwidth and the number of available codes. In

conventional asynchronous CDMA single satellite
communication systems, unique CDMA codes are assigned to
each user to ensure that information directed to one
subscriber does not interfere with information directed

5   to another subscriber. Similarly, in multiple satellite
communication systems, when two or more satellites are
serving in the same geographical location, unique CDMA
codes within the same frequency bandwidth are generally
used to distinguish each subscriber. Using the same CDMA

10   code for multiple subscribers would result in mutual
interference that would prevent the proper decoding of
information, because the omnidirectional receiving
antennas of the subscribers' terminals lack the
capability to discriminate spatially among the

15   satellites.

Summary of the Invention

A novel method and apparatus is described for
reducing the number of CDMA codes for a constellation of

20   multiple transponder platforms serving a number of
subscribers in the same service area. A coherent
processing technique synchronizes the phase of CDMA
signals arriving at a subscriber from multiple
transponder platforms to increase the code capacity and

25   thus the number of possible subscribers for most of the
multiple transponder platform systems in current use. For
example, the subscribers may use simple terminals with
nearly omnidirectional antennas for receiving signals
from multiple satellites concurrently.

30   One advantage of the present invention is that
a greater number of subscribers may be accommodated

2

within a service area without increasing the frequency spectrum or the number of CDMA codes.

Another advantage is that multiple transponder platforms may be used to enhance the signal gain for most of the subscribers in the service area.

Still another advantage is that the cost of receiving terminals is substantially reduced due to simpler operation and fewer components.

Yet another advantage is that the positions of each transponder platform and subscriber in the constellation need not be known to practice the present invention.

Still another advantage is that inexpensive terminals may be used with omnidirectional antennas without sacrificing performance.

The features and advantages summarized above in addition to other aspects of the present invention will become more apparent from the description, presented in conjunction with the following drawings.

Brief Description of the Drawings

Fig. 1 is a diagram illustrating an exemplary multiple transponder platform communications system suitable for use with the present invention.

Fig. 2 is an exemplary plot of interference noise power integrated over the entire communications channel vs. distance from the intended subscriber.

Fig. 3 is an exemplary plot of interference noise power integrated over the entire communications channel vs. distance from the intended subscriber on a larger distance scale.

Fig. 4 is an exemplary plot of interference noise power integrated over the entire communications channel vs. distance from an intended subscriber using the same CDMA codes with different CDMA code lengths.

5   Fig. 5 is an exemplary plot of interference noise power integrated over the entire communications channel vs. distance from an intended subscriber using different CDMA codes and different CDMA code lengths.

Fig. 6 is an exemplary family of plot curves of
10   ranging calibration data overhead vs. chip rate.

Fig. 7 is an exemplary family of plot curves of signal-to-noise ratio integrated over the entire communications channel vs. number of phase coherency bits.

15   Fig. 8 is an exemplary plot of Fourier processing overhead as a fraction of resource vs. data rate.

Fig. 9 is an exemplary flow chart 90 of a computer program for performing the coherent phase
20   synchronization of the present invention.

Fig. 9A is a flow chart of step 906 in Fig. 9.

Fig. 9B is a flow chart of step 910 in Fig. 9.

Fig. 9C is a flow chart of step 914 in Fig. 9.

25   <u>Description of the Invention</u>

The following description is presented to disclose the currently known best mode for making and using the present invention. The scope of the invention is defined by the claims.

30   Fig. 1 is a diagram illustrating an exemplary multiple satellite communications system suitable for use with the present invention for coherent synchronization

4

of CDMA communications signals. In this example, single transponder satellites represent transponder platforms and cellular telephones represent subscribers. Alternatively, the transponder platforms may also be

5   carrier signal frequency reflecting surfaces, and the subscribers may also be fixed or mobile terminals. Other suitable devices with sufficient field of view to cover the directions from which subscriber signals arrive and combinations thereof for relaying a signal from a gateway

10 to a subscriber may also be used, whether fixed or mobile, on the ground, in the air, or in space. Similarly, subscribers may be any suitable devices and combinations thereof employed for CDMA communications, whether fixed or mobile, on the ground, airborne, or in

15 space.

A first forward link CDMA signal 120 is transmitted by a hub or gateway 104 to satellite 106 and relayed from satellite 106 to intended subscriber 102. A second forward link CDMA signal 122 is sent by gateway

20 104 to satellite 108 and relayed from satellite 108 to intended subscriber 102. The sequence of forward link CDMA signals may be sent at different times or otherwise arranged by well known techniques to avoid mutual interference during the synchronization process.

25 Subscriber 102 logs the time each forward link CDMA signal is received according to a reference clock and inserts the time data in a return link CDMA signal corresponding to each forward link CDMA signal received.

Gateway 104 uses the time data in each return

30 link CDMA signal to calculate a corresponding time delay and performs a Fourier analysis of the return link CDMA signals to calculate a corresponding signal carrier

5

frequency shift due to Doppler. Using the time delay and
frequency shift calculations, gateway 104 inserts a delay
in the transmission of each subsequent CDMA signal from
gateway 104 so that the CDMA signals directed to intended
5   subscriber 102 arrive at intended subscriber 102 from
satellites 106 and 108 in coherent phase. The in-phase
signals add constructively at intended subscriber 102's
location, increasing the signal-to-noise ratio.

On the other hand, signals from gateway 104
10   directed to intended subscriber 102 arrive out of phase
at unintended subscriber 112 located at a distance 110
from intended subscriber 102. The phase difference is
determined by the geometry of the communications system
and distance 110 between intended subscriber 102 and
15   unintended subscriber 112. The out-phase signals
interfere with each other and appear as interference
noise.

Fig. 2 is an exemplary family of plot curves of
interference noise power vs. distance from the intended
20   subscriber using coherent phase synchronization for a
randomly distributed multiple transponder platform
constellation of seven satellites, a CDMA code length of
six, and a frequency bandwidth of 100 kHz. Using the same
CDMA code for the intended subscriber results in a
25   maximum interference noise power of 0 dB at zero distance
shown in curve 202, while using a different CDMA code for
the unintended subscriber reduces integrated interference
noise power at zero distance by about 7.5 dB as shown in
curve 204. As the distance increases, the difference in
30   interference noise power between using the same CDMA code
vs. using different CDMA codes becomes less significant.
The present invention exploits this feature to make CDMA

6

codes reusable given adequate distance between subscribers within the same service area.

Fig. 3 is an exemplary family of plot curves of interference noise power integrated over the entire
5   communications channel vs. distance from the intended subscriber on a larger distance scale. Again, using the same CDMA codes for multiple subscribers shown in curve 302 compared to using different CDMA codes shown in curve 304 does not substantially increase the interference
10   noise power relative to the signal gain achieved by coherent phase synchronization.

Fig. 4 is an exemplary family of plot curves of interference noise power integrated over the entire communications channel vs. distance from the intended
15   subscriber using the same CDMA codes with CDMA code lengths of 6 shown in curve 402 and 10 shown in curve 404. On average, longer code lengths reduce the integrated interference noise power for unintended subscribers, even when using the same CDMA codes.
20   Fig. 5 is an exemplary family of plot curves of interference noise power vs. distance from the intended subscriber using different CDMA codes and CDMA code lengths of 6 shown in curve 502 and 10 shown in curve 504. When different CDMA codes are used, the difference
25   in interference noise power vs. distance for unintended subscribers is more significant.

For synchronization of signals from multiple satellites, there is no need to determine the absolute positions of the platforms. The relative timing,
30   frequency, and phase between platforms is sufficient to perform coherent phase synchronization of CDMA signals.

Although the range is substantially the same for a forward link and the corresponding return link, the processing delays and signal channel distortions may be different.

5   To determine the range between the gateway or hub and a subscriber, the gateway includes ranging calibration data in each message sent to each subscriber via each transponder platform to establish a subscriber range corresponding to each transponder platform. The

10   subscriber receives the ranging calibration data from each transponder platform and returns a message to the gateway containing the time read from a reference clock.

Fig. 6 is an exemplary family of plot curves of ranging calibration data overhead vs. chip rate for a

15   range rate of 60 m/sec and a data rate of 144 kHz for 10 satellites shown in curve 602, 5 satellites shown in curve 604, 2 satellites shown in curve 606, and 1 satellite shown in curve 608.

The gateway receives the subscriber message and

20   performs a coherent phase synchronization calculation for each subscriber via each satellite. The gateway uses the coherent phase synchronization calculations to delay the signals transmitted to each satellites for each subscriber so that the signals for each subscriber from

25   all of the transponder platforms arrive at each subscriber in coherent phase.

The coherent phase synchronization calculations include the steps of comparing the transmission time in the range calibration data with the reception time read

30   from the subscriber's reference clock. The time difference is included in the subscriber's return signal. Several such time differences are measured and sent back

8

to the gateway. The fraction of the chip time required
for range calibration data is given substantially by:

$$\frac{T_x}{T_c + T_x} \tag{1}$$

where T_x is message time allocated for the range

5 calibration data, and T_c is message time allocated for

communications data.

The accuracy of the ranging calibration is given

substantially by:

$$\frac{C_w}{\sqrt{n_x}} \tag{2}$$

10 where C_w is the chip width, and n_x is the number of time

differences measured. For a maximum range rate of 60

m/sec and a data rate of 144 KHz, a typical value for the

fraction of chip time required for ranging calibration

data is less than 5%.

15   The parameters used for the phase

synchronization calculation are:

      n_b = number of phase bits required to achieve

phase coherency

      δ_f = total frequency uncertainty

20   n_b depends on the number of platforms and the

desired signal-to-noise ratio (typically 20 dB). T_x is the

product of n_b times the chip duration.

δ_f represents the combined effects of CDMA carrier oscillator stability and relative motion among the gateway, the transponder platform, and the subscriber.

5   The Fourier period is determined by the required frequency accuracy substantially from the following formula:

$$\delta_f = \frac{1}{T_c + T_x} \tag{3}$$

The total number of samples required for the Fourier

10 processing determines the fraction of the chip time required for range calibration data given by (1).

Fig. 7 is an exemplary family of plot curves of signal-to-noise ratio vs. number of phase coherency bits used in the ranging calibration data for 10 satellites

15 shown in curve 702, 5 satellites shown in curve 704, 2 satellites shown in curve 706, and 1 satellite shown in curve 708.

Fig. 8 is an exemplary plot of Fourier processing overhead as a fraction of resource vs. data

20 rate for 10 satellites shown in curve 802, 5 satellites shown in curve 804, 2 satellites shown in curve 806, and 1 satellite shown in curve 808. In this example, the range acceleration is 2 m/sec^2. As the number of

10

transponder platforms increases, the Fourier processing

overhead increases, but the difference becomes less

significant with higher data rates. At a data rate of 144

KHz, for example, the overhead is only about 0.1% for a

5   constellation of five satellites having a relative range

rate of 2 m/sec^2. This overhead is insignificant compared

to the typical resource fraction of chip time of 10%

required for ranging calibration data at the same data

rate at a chip rate of 4 mHz. At a range rate of 30

10   m/sec, the required resource is about 3%, and at 60

m/sec, about 6% assuming sequential processing.

Alternatively, the ranging calculations may be done in

parallel in the return link to reduce the Fourier

processing overhead.

15   Fig. 9 is an exemplary flow chart 90 of a

computer program for performing the coherent phase

synchronization of the present invention. At step 902 a

transponder platform index is initialized that increments

up to the total number of transponder platforms in the

20   constellation.

At step 904 processing is initialized for the

next transponder platform. In this step statistical data

is cleared comprising the average signal propagation

delay, frequency, and phase between the gateway and each

11

subscriber within the transponder platform's coverage
area. A subscriber index is initialized that increments
up to the total number of subscribers.

At step 906 the processing for each subscriber

5   within the transponder platform's coverage area is
performed. Fig. 9A shows step 906 in further detail. At
step 952 the gateway transmits a ranging signal to the
subscriber. The ranging signal may contain an
identification code unique to the subscriber to avoid

10 interference from other subscribers receiving the ranging
signal. When the subscriber receives the ranging signal
at step 954, it computes the signal propagation delay and
phase information relative to a local reference clock. At
step 956 the subscriber transmits the signal timing and

15 phase information to the gateway. When the gateway
receives the information at step 958, it computes the
signal timing, frequency, and phase for the subscriber
relative to the transponder platform using, for example,
statistical averaging or Fourier analysis. Other methods

20 may be used according to well known techniques.

Referring back to Fig. 9, the subscriber index
is incremented at step 908. If not all subscribers have
been processed, processing continues from step 906 above.
Otherwise the processing common to all the subscribers

12

within the transponder platform's coverage area is performed at step 910.

Fig. 9B shows step 910 in further detail. At step 962 the gateway computes the relative motion

5 statistics of the transponder platform relative to the subscribers for updating signal timing estimates.

Referring back to Fig. 9, the transponder platform index is incremented at step 912. If not all transponder platforms have been processed, processing

10 continues at step 904 above. Otherwise processing continues at step 914.

Fig. 9C shows step 914 in further detail. At step 972 the gateway updates the average signal timing, frequency, and phase data for all subscribers and all

15 transponder platforms. At step 974 the gateway transmits reference clock corrections to each subscriber to synchronize the signal phase of each subscriber with respect to the gateway. At step 976 the gateway continues transmitting communications messages to each subscriber

20 via each transponder platform using the delays calculated to achieve coherent signal reception by each subscriber.

By the process described above the gateway delays the transmission of a CDMA signal for an intended subscriber to each transponder platform or satellite in

13

the constellation by the correct amount to achieve phase

coherency of the signals at the subscriber's location. In

addition, the gateway may also adjust the frequency of

the CDMA signal for the intended subscriber to each

5   transponder platform to compensate for doppler shift so

that the signals arriving at the intended subscriber from

each transponder platform have the same frequency.

The synchronization process described above is

preferably done in the background to minimize

10   interruption of communications messages. When

computations are completed for all transponder platforms

in the constellation, processing is terminated until

another iteration is performed to accommodate changes in

position and motion of the transponder platforms and the

15   subscribers.

Fig. 10 shows an embodiment of the present

invention in a gateway 1000 for performing the functions

described in Fig. 9. Transmitter 1002 transmits the

ranging and delayed communications signals to the

20   subscriber. Receiver 1004 receives the signal timing and

phase information from the intended subscriber. The

signal timing, frequency, and phase are calculated

respectively by time shift calculator 1006, frequency

shift calculator 1008, and phase shift calculator 1010.

14

CDMA sequencer 1012 transmits the reference clock corrections to each subscriber to synchronize the signal phase of each subscriber with respect to gateway 1000.

Other modifications, variations, and arrangements of the present invention may be made in accordance with the above teachings other than as specifically described to practice the invention within the scope of the following claims.